SCALABILITY PLANNING FOR RECONFIGURABLE MANUFACTURING SYSTEM USING SIMULATED ANNEALING

A Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of

B. Tech.

(Mechanical Engineering)

By

AMIT KUMAR MARANDI

Roll No. 109ME0384

Department of Mechanical Engineering

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

JUNE, 2013

SCALABILITY PLANNING FOR RECONFIGURABLE MANUFACTURING SYSTEM USING SIMULATED ANNEALING

A Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of

B. Tech.

(Mechanical Engineering)

By

AMIT KUMAR MARANDI

Roll No. 109ME0384

Under the supervision of

Dr. Saroj Kumar Patel

Associate Professor

Department of Mechanical Engineering, NIT, Rourkela

Department of Mechanical Engineering

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

JUNE 2013

National Institute of Technology
Rourkela

C E R T I F I C A T E

This is to certify that the work in this thesis entitled ***Scalability Planning for Reconfigurable Manufacturing System using Simulated Annealing*** by **Amit Kumar Marandi,** has been carried out under my supervision in partial Fulfillment of the requirements for the degree of **Bachelor of Technology** in *Mechanical Engineering* during session 2012 - 2013 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela. To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

Dr. Saroj Kumar Patel
(Supervisor)
Associate Professor
Dept. of Mechanical Engineering
National Institute of Technology
Rourkela - 769008

ACKNOWLEDGEMENT

It's a great pleasure to express my deep sense of gratitude and respect to my supervisor Prof. Saroj Kumar Patel for his excellent guidance, suggestions and support through out the project. I feel extremely lucky to be able to work under the guidance of such a dynamic personality. I am also thankful to Prof. K.P. Maity, H.O.D, Department of Mechanical Engineering, N.I.T., Rourkela for his constant support and encouragement.

Last but not the least, I extend my sincere thanks to all other faculty members, my senior research fellow and my friends at the Department of Mechanical Engineering, NIT, Rourkela, for their help and valuable advice in every stage for successful completion of this project report.

C O N T E N T S

ABSTRACT

This thesis is a review of manufacturing techniques and introduction of reconfigurable manufacturing systems. A new paradigm is designed for the rapid adjustment of production capacity and functions, according to condition of market or, market demand. A definition of reconfigurable manufacturing systems is given and an overview of all available manufacturing systems is given. The new techniques and characteristic of reconfigurable manufacturing system are described along with its key role in future manufacturing system. A mathematical model is described for calculating RMS with recommended structure. A scalability planning for RMS using simulated annealing is done in this project work and the results are found to be satisfactory.

LIST OF FIGURES AND TABLES

Figures:

Tables:

Chapter 1
Introduction

Chapter 1

1. INTRODUCTION

1.1 Requirements of today's manufacturing systems

A manufacturing system transform from raw materials to the required products. Its main objective is to given maximum benefit with shorter time. The requirements are:

A. **Short lead-time:** Product lead-time affects the function of a manufacturing system in different ways.

B. **Variants:** Products have more versatile and customization. A manufacturing system is need to produce more variants to meet the fragmented.

C. **Low and fluctuating volume:** They fall due to the life cycle of a new product becomes shorter and the durability of the products becomes longer and the product customization has fragmented the entire market demands into small portions.

D. **Low price:** The price of a product varies more than others in the market. The customer wants to purchase low-price product with the same quality and service. On the other hand the time heavily depended on the time of the manufacturing.

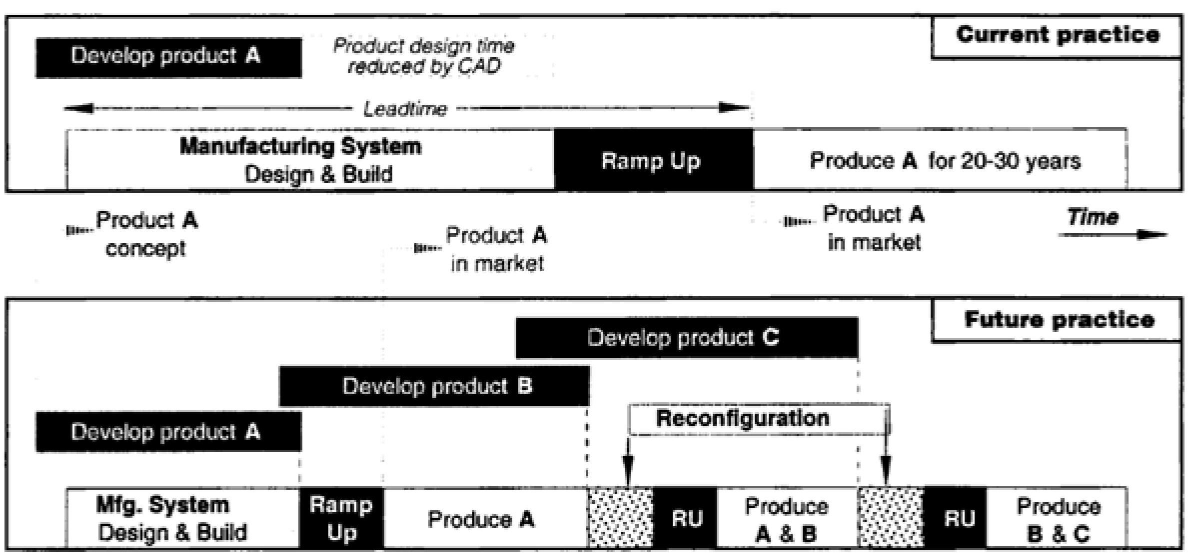

Fig 1: Production development time was reduced dramatically by CAD [1].

1.2 Definition of Reconfigurable Manufacturing System:

The new type of manufacturing system, which we call the reconfigurable manufacturing system, will allow not only flexibility but also changing the system itself. These systems carry basic process modules- hardware and software-that will be arranged quickly and reliably. These systems become obsolete, because they will enable the rapid changing of system component and rapid addition of application-specific software modules.

1.3 Comparison of various manufacturing systems:

Reconfigurable manufacturing system is not more expensive than flexible manufacturing systems. Unlike other types of manufacturing systems, RMS aims to be installed exactly production capacity and functionality needed, and may upgraded in future, when needed. RMS enables production of complex parts type and production of variety of parts. As shown in Fig. 2 capacity versus functionality trade-off, RMSs may, in many cases, occupy a middle ground between DMSs and FMSs. The capacity and functionality is not fixed in RMS, and it does not have a fixed hardware/software.

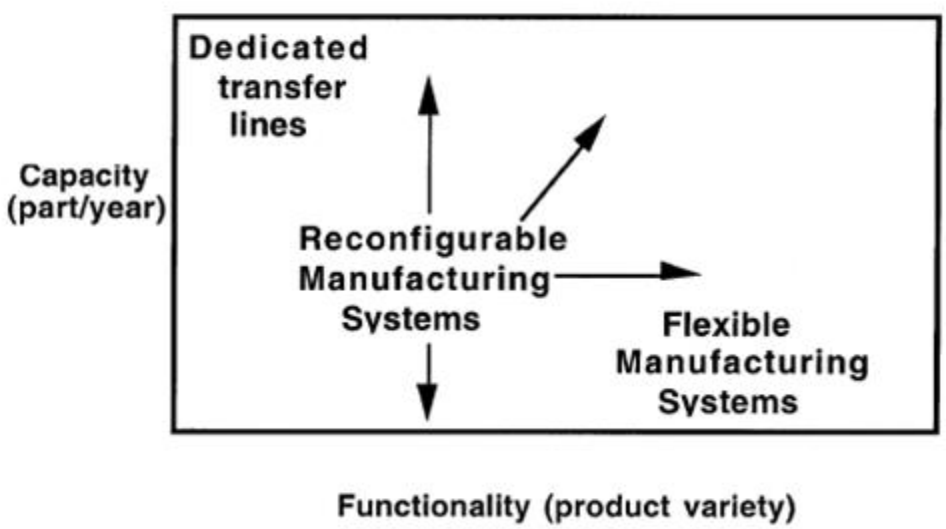

Fig. 2: Mapping several types of manufacturing systems in capacity-functionality coordinates[1].

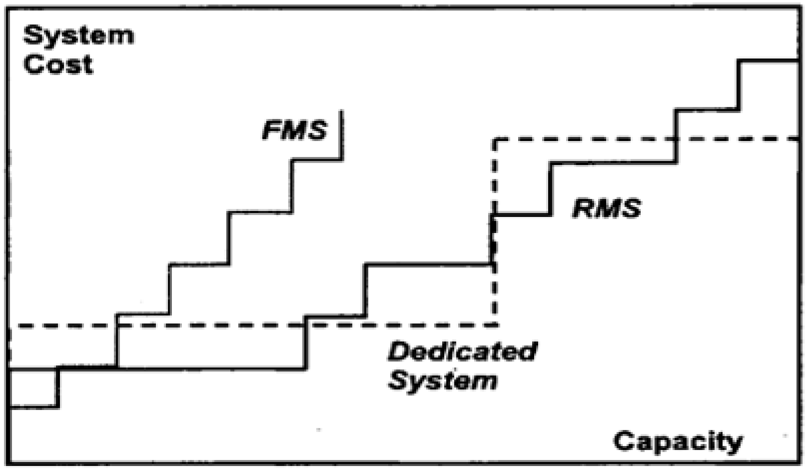

Fig. 3: Manufacturing system cost versus capacity[1].

Table 1. Key features of a reconfigurable manufacturing system

1. Modularity:	Design all system components, both software and hardware, is to be modular.
2. Integrability:	Design systems and components of both ready integration an future introduction of new technology.
3. Convertibilty:	Allow quick changeover between existing products and quick system adaptability for future products.
4. Diagnosability:	Identify quickly the sources of quality and reliability problems.
5. Customization:	Design the system capability and flexibility (hardware and controls) to match the application.

Table 2. Summary of definitions and objectives

Systems (machining/manufacturing)	Definitions and Objectives
Machining system	One or more metal removal machine tools and tooling, and auxiliary equipment (e.g., material handling, control, communications), that operate in a coordinated manner to produce parts at the required volumes and quality.
Dedicated machining systems	A machining system is designed for production of a specific part, and which uses transfer line technology with fixed tooling and automation. The economic objective of a DMS is to cost-effectively produce one specific part type at the high volumes and the required quality.
Flexible manufacturing systems	A machining system configuration with fixed hardware and fixed, but programmable, software to handle changes in work orders, production schedules, part-programs, and tooling for several types of parts. The economic objective of a FMS is to make possible the cost-effective manufacture of several types of parts, which can change overtime, with shortened changeover time, on the same system at the required volume and quality.
Reconfigurable manufacturing systems	The objective of an RMS is to provide the functionality and capacity that is needed, when it is needed. Thus, a given RMS configuration can be dedicated or flexible, or in between, and can change as needed. An RMS goes beyond the economic objectives of FMS by permitting: (1) reduction of lead time for launching new systems and reconfiguring existing systems, and (2) the rapid manufacturing modification and quick integration of new technology and/or new functions into existing systems.

Chapter 2
Literature Review

This chapter deals with the background information to be considered in this thesis and focuses on the relevance of the present study. This treatise embraces some related aspects of reconfigurable manufacturing system.

1. Classification of configurations
2. Calculating the number of RMS configurations
3. Reconfigurable assembly systems

2.1 Classification of configurations:

Classifying configurations requires determining the number of possible configurations when the daily demand, Q (parts/day), and the total machining time for the part, t (min/part), are given. In reality, machining times vary widely depending on the equipment involved, but, to begin we assume these are given. The minimum number of machines, N, needed in the system is calculated by the equation

$$N = \frac{Q \times t}{\text{Min/day available} \times \text{Machine reliability}} \qquad (1)$$

The following calculations assume 100% reliability of all pieces of equipment (i.e., machine reliability = 1). The resulting number of machines calculated by Eq. (1) must be rounded to the next larger integer. For example, if 500 parts per day are needed and the processing time for each part is 9.5 min, at least five machines are needed in the system assuming working time of 1000 min/day. In the general case the total number of configurations for N machines is huge. When plotted on a logarithmic scale, the number of configurations increases almost linearly with the number of machines, as shown in Fig. 4. The number of possible RMS configurations is much smaller, as indicated in the table in Fig. 4 [1].

Number of machines	Number of possible configurations	Number of RMS configurations
2	2	2
4	15	8
6	170	32
8	2,325	128
10	**35,341**	**512**

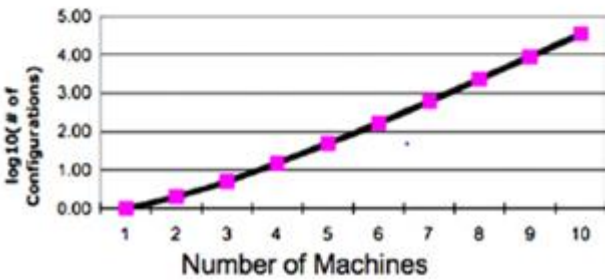

Fig. 4: Total number of system configurations for different numbers of machines [2].

2.2 Calculating the number of RMS configurations:

Professor Nam Suh laid out a theoretical framework for the design of large systems [2]. Yet as he himself wrote, ‘‘the goal is to develop a thinking design machine and create pedagogical tools for teaching’’. A few years later, Jacobsen et al. [3] recognized that ‘‘the design of a production system is a challenging activity’’. Yet the authors of this article did not propose a mathematical method or even a design procedure. Here we propose a practical mathematical method that engineers can easily utilize for designing reconfigurable manufacturing systems.

We have already seen that the minimum number of machines N required in the system can be easily calculated by solving Eq. (1). However, as shown in Fig. 4, the number of all possible configurations with N machines is enormous. After a thorough mathematical study of system configurations, we conclude the following:

Closed equations for calculating the number of configurations with N machines exist only for RMS-type configurations. The basic equations for calculating the number of possible RMS configurations are given below. K, the number of possible RMS configurations with N machines arranged in up to m stages is calculated by:

$$K = \sum_{m=1}^{N} \binom{N-1}{m-1} = 2^{N-1} \tag{2}$$

K, the number of possible configurations with N machines arranged in exactly m stages is calculated by:

$$K = \frac{(N-1)!}{(N-m)!(m-1)!} \tag{3}$$

For example, for N = 7 machines arranged in up to 7 stages, Eq. (2) yields K = 64 configurations, and if arranged in exactly 3 stages, Eq. (3) yields K =15 RMS configurations. The mathematical results of these two equations for any N and m may be arranged in a triangular format, known as a Pascal triangle, shown in Fig. 5.

The numerical value of each cell in the Pascal triangle is calculated as follows. The numerical value corresponding to N machines arranged in m stages is calculated by:

The value for N machines in m stages = (the value for N – 1 machines in m − 1 stages) + (the value for N − 1 machines in m stages).

For example, in Fig. 5, the cell of N = 5 and m = 3 shows 6, which is the sum of 3+3 of the previous line of N−1 = 4 machines with 2 and 3 stages.

The triangle also allows the designer to immediately visualize the number of possible RMS configurations for N machines arranged in m stages. For example, there are 15 RMS configurations when 7 machines are allowed to be arranged in exactly 3 stages. In addition, the Pascal triangle allows the designer to immediately calculate the number of possible RMS configurations for N machines arranged between i stages and j stages (i, j<N).

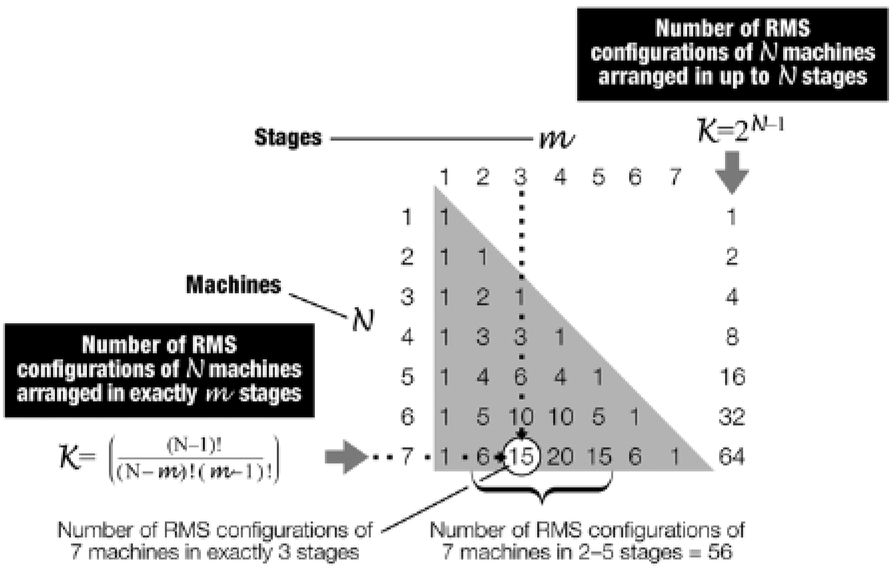

Fig. 5 The Pascal triangle is helpful in calculating number of RMS configurations[3].

2.3 Reconfigurable assembly systems:

Product manufacturing consists of two main steps. First, components are fabricated using different methods, such as casting, machining, injection moulding or metal forming. Second, these components are assembled or joined together using methods such as welding. Assembly systems comprising many stations for assembling a product are utilized in manufacturing virtually all types of durable goods, such as automobiles or office furniture. The product is fixed by clamps and transferred on the fixture through the assembly system [4]. Reconfigurable assembly systems are those that can rapidly change their capacity (quantities assembled) and functionality (product type, within a product family) to adapt to market demand. For example, Bair et al. described a reconfigurable assembly system designed to produce different combinations of heat exchangers for industrial refrigerator systems [5].

Each product in a family requires planar assembly, namely all parts are lying in a single geometric plane (e.g., printed circuit boards), and the system may consist of SCARA type robots [6].

A key feature of reconfigurable assembly systems is a modular conveyor system that can operate asynchronously and be reconfigured to accommodate a large variety of component choices according to the product being assembled [7].

Webbink and Hu pioneered a set of algorithms to quickly generate possible assembly system configurations and assign assembly tasks to these configurations [8].

Hu and Stecke studied a two-stage RMS configuration [9].

Chapte3

Optimization Method

3.1 Simulated annealing:

The simulated annealing simulates the process of slow cooling rate molten metal to achieve the minimum function value in a minimization problem. Simulated annealing (SA) has been found many applications in solving difficult optimization problems. For example, SA has been implemented successfully in: travel salesmen problem [10, 11]; the quadratic assignment problem; multi- dimensional assignment problems [12, 13]; scheduling problems of a wide variety and manufacturing process planning problems [14, 15]. These examples show that the nature of the problems that have been solved through applications of SA is wide and cuts across the spectrum of combinatorial, N-P Hard and N-P Complete problems. Therefore, simulated annealing is a potential candidate for solving difficult optimization problem. Simulated annealing (SA) is usually implemented as a trajectory- based search technique [16]. It was first introduced by Kirkpatrick et al. [17].

Simulated annealing is a point-by-point method. The cooling phenomenon is simulated by controlling a temperature like parameter introduced with the concept of the Boltzmann probability distribution. According to in thermal equilibrium T a system has its energy distributed probabilistically according to $P(E) = \exp^{(E/kT)}$, where k is the Boltzmann constant.

3.2.1 Algorithm:

Step 1: Choose an n initial point $x^{(0)}$, and a termination criterion Є. Set T a sufficiently high value, number of iterations to be performed at a particular temperature n, and set t=0.

Step 2: A neighbouring point $x^{(t+1)}= N(x^{(t)})$ is calculated.

Step 3: If $\Delta E=E(x^{(t+1)})-E(x^{(t)}) < 0$, set t=t+1;
Else create a random number (r) in the range (0,1). If $r \leq \exp(\Delta E/T)$ set t=t+1;
Else go to step 2.

Step 4: If $|x^{(t+1)}-x^{(t)}| <$ Є and T is small, **Terminate**;
Else if (t mod n) = 0 then lower T according to a cooling schedule.
Go to Step 2;
Else go to Step 2.

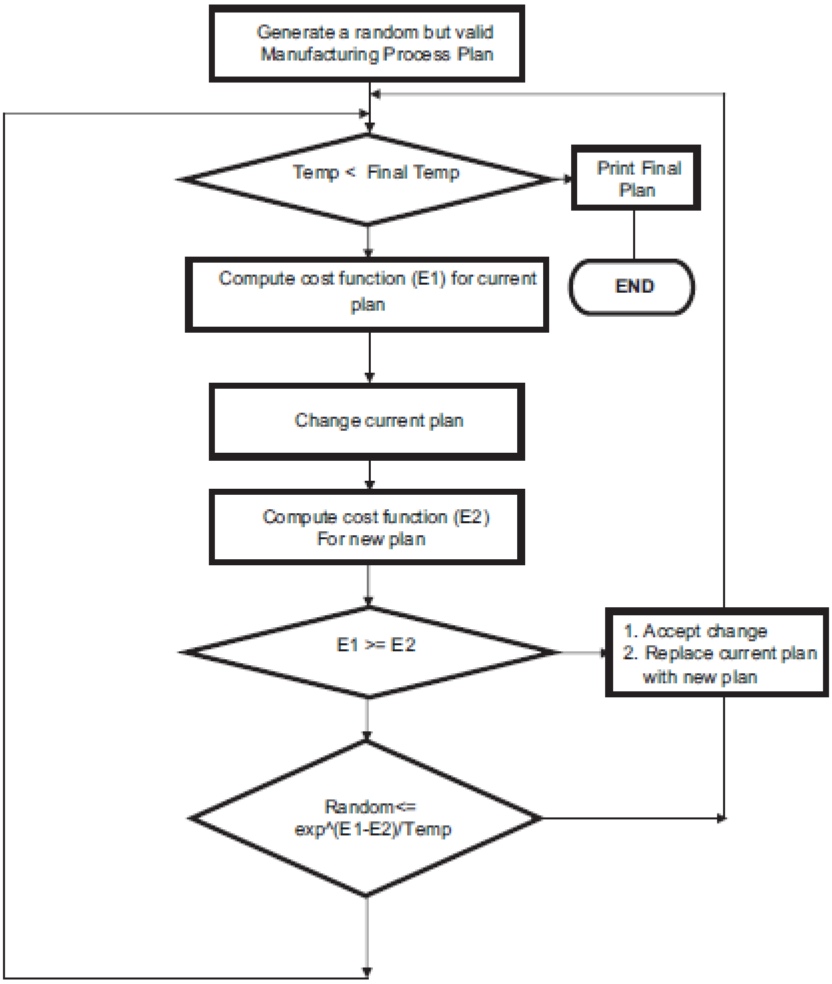

Fig. 6. Flow chart for the simulated annealing algorithm implemented [16].

Chapte4

Results and Discussion

4.1 Configuration information:

Number of stages = L;
number of machines in each stage = Ni,
where i = 1,2, . . ., L; maximum number of machines allowed in each stage Mi, i = 1,2, . . .,L

4.2 Decision variables:

M[i] = number of machine being added to stage i, $1 \le i \le L$; M[i] > 0 for adding machines, and M[i] < 0 for removing machines from systems[18].

4.3 Optimization model:

The objective of scalability planning is to minimize the number of machines needed to meet a new market demand. This can be expressed by Eq. (5):

$$\text{Minimize} \quad \sum_{i=1}^{L} (Ni + M[i]) \tag{5}$$

The number of machines added to, or removed from each stage must not exceed the maximum limit. $M[i] \le M\max[i], \forall i = 1, 2, \ldots, L$

4.4 Basic structure of simulated algorithm:

```
procedure  Simulated_Annealing; {Minimization}
begin
        Choose_a_starting_solution (i_start ∈L);
        initialize(T0, M0);
        k:=0;
        i:=i_start;
        repeat
              for m:=1 to M_k do
                        begin
                                        generate(j∈L_i);
                                        if F(j) ≤ F(i) then i:=j
                                        else
                                        if then i:=j;
                        end;
               k:=k+1;
               Calculate_M(M_k);
               Calculate_Temperature(T_k);
         until termination criterion;
end;
```

Table 3: simulation of optimization problem using Visual C++

Number of stages = **L**;	number of machines in each stage = **Ni,**	**M[i]** = number of machine being added to stage i
1	7	10
2	3	3
3	2	2
4	5	6
5	6	6
6	9	10
7	1	0
8	4	6
9	14	15
10	11	15
11	3	11
12	7	10
13	11	15
14	2	2
15	3	2
16	4	5
17	6	4
18	7	10

Illustrative example solved by hand:

Number of stages = 3;
number of machines in each stage =2
We have to calculate number of machine being added to stage

Minimize, $f(x_1,x_2,x_3) =(2+x_1)+(2+x_2)+(2+x_3)$
where ' x_i ' is equal to number of machine is to be added in each stage.
i=1,2,3

Solution:

initial point $x^{(0)}= (0,0,0)^T$

termination factor $\epsilon =10^{-2}$

initial temperature T =12

set t=0

A neighbouring point $x^{(t+1)}= N(x^{(t)})$ is calculated. Usually, a random point in the neighbourhood is created.
If $\Delta E=E(x^{(t+1)})-E(x^{(t)}) < 0$, set t=t+1;
Else create a random number (r) in the range (0,1). If $r\leq \exp(\Delta E/T)$ set t=t+1;
Else go to step 2.
If $|x^{(t+1)}-x^{(t)}|< \epsilon$ and T is small, **Terminate**;

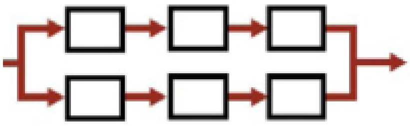

Fig 7: 3 stage having 2 machines in each stage [18]

Table 4: simulation of illustrative example

t	$x^{(t)}$	$E(x^{(t)})$	ΔE	T
0	(0,0,0)	6	0	12
1	(0.037,-0.086,0.046)	5.997	-0.003	6
2	(-0.389,-1.896,0.452)	4.167	-1.83	3
3	(-0.114,-0.956,0.889)	1.652	1.652	3
4	(0.813,-1.382,1.035)	6.466	0.647	1.5
5	(1.02,-0.335,0.9)	7.585	1.119	0.75
6	(0.74,0.092,1.13)	7.962	0.337	0.75
7	(0.72,0.103,1.13)	7.936	-0.026	0.375
8	(0.746,0.1,1.002)	7.848	-0.088	0.1875
9	(0.97,0,1)	7.97	0.122	0.09375
10	(0.98,0,1)	7.98	0.01	0.046875
11	(0.99,0,1)	7.99	0.01	0.023

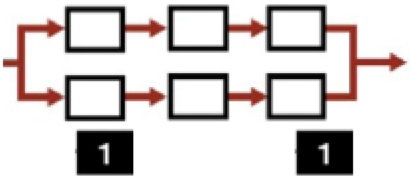

Fig 8: final diagram of machine added [18].

Chapter 5

Conclusions

The present work done is focused on scalability planning for RMS using simulated annealing. The scalability planning for RMS using simulated annealing algorithm aims minimizing the number of machines needed to meet a new market demand. The algorithm has been encoded in Visual C++ 2010 edition. In most of the cases the algorithm converged within 10-12 iterations. The computational time has been reasonable and the solutions obtained are near to optimal. The exploitative searching ability and processing power of simulated annealing (SA) has extensive potential approach to manufacturing.

Bibliography

[1] Zhu, X. W., 2005. Calculating the number of possible system configurations. Tech.rep., ERC/RMS.

[2] Suh, N. P., 1995. Design and operation of large systems". Journal of Manufacturing Systems, 14(3), pp. 203-213.

3] Jacobsen, P., Pedersen, L. F., and an C Witfelt, P. E. J. Philosophy regarding the design of production systems". Journal of Manufacturing Systems, 20(6).

[4] Camelio, J. A., Hu, S. J., and Ceglarek, D. Impact of fixture design on sheet metal assembly".

[5] Bair, N., Kidwai, T., Mehrabi, M., Koren, Y., Wayne, S., and Prater, L., 2002. Design of a reconfigurable assembly system for manufacturing heat exchangers". Japan USA flexible automation international symposium.

[6] Koren, Y., ed., 1986. Trajectory interpolators for SCARA-type robot, Vol. 1, The14th NAMRC.

[7] Hains, C. L., 185. An algorithm for carrier routing in a flexible material-handling system". IBM Journal of Research and Development, 29(4), pp. 356-362.

[8] Webbink, R. F., and Hu, S. J., 2005. Automated generation of assembly system-design solutions". IEEE Transactions on Automation Science and Engineering, 2(1), pp. 32-39.

[9] Hu, S. J., and Stecke, K. E., 2009. Analysis of automotive body assembly system configurations for quality and productivity". International Journal of Manufacturing Research, 4, pp. 117-141.

[10] Hoffman, A., and Wolfe, P., 1985. "The traveling salesman problem, pp. 1-16.

[11] Wei-Bo, Y., and Yan-Wei, Z., 2010. Improved simulated annealing algorithm for tsp". Computer Engineering and Applications, 46(15), pp. 34-36

[12] Clemons, W. K., Grundel, D. A., and Jeffcoat, D. E. Applying simulated annealing to the multidimensional assignment problem". In Theory and algorithms for cooperative systems, A. Editor, ed. pp. 1-3.

[13] Huang, X., 2004. Cooperative optimization for solving large scale combinatorial problems". In Theory and algorithms for cooperative systems, D. Grudel, R. Murphy, and P. M. Pardalos, eds., series on computers and operations research. World Scientific, Singapore, p. 4.

[14] Hang, Y. F., and Nee, A. Y. C., 2001. Applications of genetic algorithms and simulated annealing in process planning optimization". In Computational intelligence in manufacturing handbook, Wang and Kusiak, eds. p. 4.

[15] Lian, K. L., Zhang, C. Y., Gao, L., Xu, S. T., and Sun, Y., 2011. A cooperative simulated annealing algorithm for the optimization of process planning". Advanced Materials Research, pp. 181-182.

[16] Blum, C., and Roli, A., 2003. Metaheuristics in combinatorial optimization: overview and conceptual comparison". ACM Computing Surveys, 35(3), pp. 268-308.

[17] Kirkpatrick, S., Gelatt, C. D. J., and Vecchi, M. P., 1983. ".Optimization by simulated annealing, 220(4598), pp. 671-679.

[18] Koren, Y., ed.,2011. Scalability planning of reconfigurable manufacturing system, The University of Michigan, Ann Arbor, USA, pp. 83-91.